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Compact and Lightweight Multigrid Collimators for a Satellite-Borne Solar X-Ray Spectrometer Experiment

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14 August 1978

Interim Report

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This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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Multigrid X-ray collimators with fields of view of 20 arc sec and 1 arc min were designed and built for use in the CRLS-229 X-ray Spectrometer/Spectroheliograph experiment aboard the USAF STP P78-1 satellite. A systematic design approach resulted in collimators that were usable in the 0.5-5 keV range with no off-axis transmission for angles below 40 arc min. The mechanical design combined a firm and rigid mount with a capability for fine alignment adjustments during the assembly process. The collimators were provided with optical sun detectors to verify instrument pointing and reference mirrors for coalignment next page

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with one another and with the spacecraft pointing reference sensors. They were subjected to a comprehensive series of tests to assure their proper functioning and ability to survive launch and on-orbit environments.

PREFACE

A. DeVito and W. Eng played important roles in assembling and aligning the collimators. Eng, P. B. Landecker, H. R. Rugge, and R. L. Williams assisted in the testing program. The ray tracing computer program, COLLIE, was written by J. H. Underwood. We are especially grateful to Dr. R. L. Blake of Los Alamos Scientific Laboratories, who provided us with the detailed information needed to set up the alignment and assembly system. To a great extent our design is based upon principles set forth by Dr. Blake and his group.

CONTENTS

FIGURES

I. Introduction

The CRLS-229 experiment on the USAF STP P78-1 satellite is a complex collection of X-ray instruments designed to study solar activity. Two of the instrument packages, SOLEX, consisting of two crystal spectrometers, and MAGMAP, consisting of two proportional counters, require fine collimation of the incident X-rays. SOLEX is designed to map solar X-rays with 20 arc sec and 1 arc min resolution by using the spacecraft rastering capability, and to provide X-ray spectra of selected features in the solar atmosphere, again with 20 sec and 1 min resolution. MAGMAP is designed to use filters to make daily whole-sun maps in the emission lines of highly ionized magnesium with the SOLEX one arc minute collimator. Further details of the CRLS-229 instrumentation may be found in a report by Landecker, et al. (1978).

The experimental objectives of the SOLEX and MAGMAP instruments demanded relatively small and lightweight collimators of 20 arc sec and 1 arc min (FWHM) fields of view. This report describes the multigrid collimators designed to meet this need. Figure 1 is a photograph of a completed unit. Section II describes the design approach chosen to meet the scientific objectives, Section III treats the mechanical design, and Section IV discusses alignment. Section V gives a brief description of the ancillary optical equipment mounted on the collimators, and Section VI sets forth the testing program. Section VII summarizes the report.

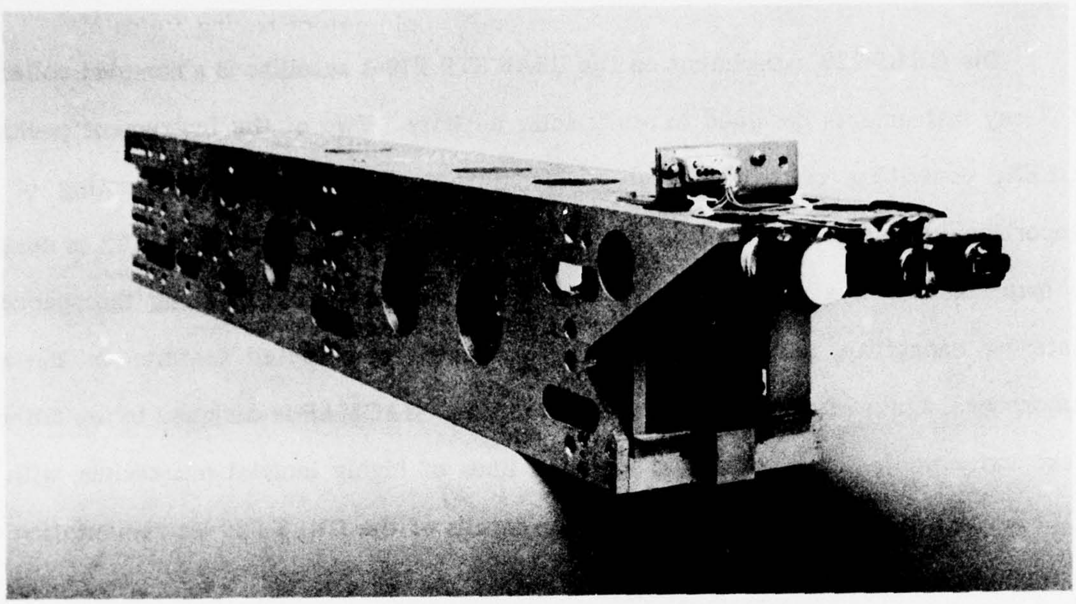

Fig. 1. Flight Spare Collimator. This collimator has one arc min resolution, but is configured like the flight 20 sec unit (see Section VI).

II. Scientific Design Approach

The objective was to provide two multigrid collimators having fields of view of one arc minute and 20 arc seconds. Early in the program we decided that, with the exception of the grids, the components for both collimator assemblies should be identical. This provided more than a cost saving. We realized that, in view of the short time available to design and build a complex experiment, we might have difficulties with the 20 arc sec unit. The common design allowed us the option of delivering two one arc min devices in the event of such difficulties. Since the components of the two collimators were to be identical, the 20 arc sec one imposed the design constraints.

Figure 2 illustrates a system for placing the grids to provide collimation free of leaks out to a maximum angle θ_M. The FWHM collimator resolution is W/L for square grid holes. The CRLS-229 collimators were constrained to $L \leq 53$ cm; we chose $L = 52.40$ cm so that W's of 51 and 152 μm, respectively, gave resolutions of 20 arc sec and 1 arc min. As illustrated in Figure 2 (see McGrath, 1968), the N intermediate grids (excluding the two end ones) are placed according to the formula,

$$(L - \ell_n) = \frac{W}{W + t} (L - \ell_{n-1}) \qquad (\ell_o = 0), \qquad (1)$$

so that the nth grid just intercepts the first ray passing above (in Figure 2) the (n-1)th grid. The design forbids side transmission lobes for all angles smaller than θ_M (Figure 2), given by

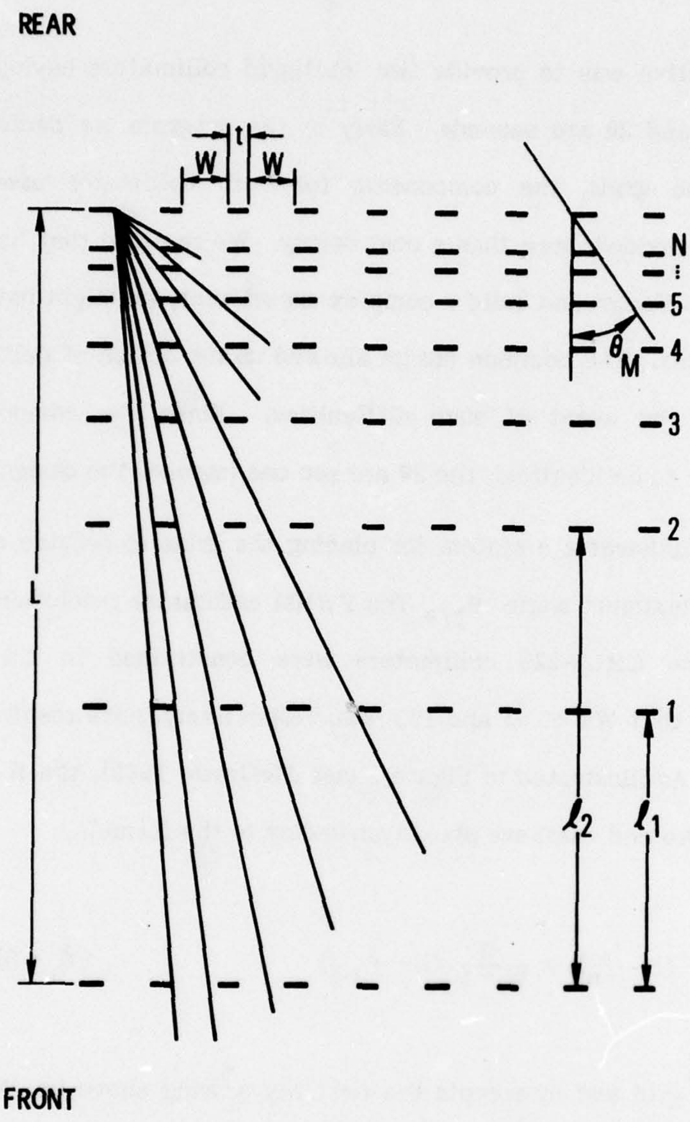

Fig. 2. Optimum Procedure for Placing Collimator Grid

$$\theta_M \approx \tan \theta_M = \frac{t}{L - \ell_N} = \left(\frac{W+t}{W}\right)^N \frac{t}{L} \,. \qquad (2)$$

Solving equation (2), we obtain a lower limit on the number of intermediate grids required:

$$N \geq \frac{\log\left(\frac{L\,\theta_M}{t}\right)}{\log\left(\frac{W+t}{W}\right)} \,. \qquad (3)$$

For square grid holes the on-axis transmission must be less than or equal $(W/W+t)^2$, so it is advantageous to maximize W/t. Unfortunately, when W/(W+t) is increased, N also increases and grids become closely packed near the rear of the collimator. For a 20 arc sec collimator with $\theta_M \geq 32$ arc min (one solar diameter), *this latter difficulty presented* severe enough assembly and alignment problems that we decided to let W equal t. The common housing design then required W = t for the other collimator as well. One minute and 20 second resolutions were obtained with t = 51 μm and 152 μm, respectively.

Experience has taught us that grid hole sizes cannot be maintained to arbitrary accuracy and that small alignment errors are inevitable. The procedure described above can be modified to provide a margin for such errors. Figure 2 shows that grid n may be placed forward of its position as determined by Equation (1) provided that all higher numbered grids are placed no closer to the rear of the collimator than would be required by Equation (1) with the changed position of grid n. This condition is exploited by substituting a larger number for W/(W+t) in Equation (1); the collimator is designed as if

the grid holes were somewhat larger than the bars. After a series of trade-off studies we arrived at a design with W/(W+t) replaced by .575; this allowed an effective hole-size error margin of 7.6 μm for the 20 sec collimator and 22.9 μm for the one arc minute collimator. A θ_M of 40 arc min then required N = 9 for a total of 11 grids. This still resulted in a considerable packing of grids at the rear of the collimator. We alleviated this difficulty by moving grid 8 to a position forward of grid 1. This deviation from the design was checked using COLLIE, a multigrid collimator ray tracing computer program. The collimator parameters are given in Table I. In the table the grids are renumbered so that those closest the front have the lowest numbers.

The physical properties of the grids limit the X-ray energy range over which the collimator is useful. The grid material and its thickness place an upper limit on the energy of X-rays absorbed by the grid. The CRLS-229 grids, manufactured by Buckbee-Mears, are of nickel with a thickness of 2.00×10^{-2} gm/cm^2. At the shortest SOLEX wavelength, 3.12Å, the normal incidence transmission of a single grid is 1.6×10^{-3}; thus the collimator works well throughout the SOLEX energy range. Since the MAGMAP experiment works at wavelengths longward of 8Å, its demands on the collimator are less severe than those of SOLEX. At the long wavelength end, diffraction effects limit the collimator performance. Blake, et al. (1976) have set a crude criterion for diffraction effects to be ignorable:

$$\lambda < \frac{W^2}{2L} , \tag{4}$$

TABLE I

CRLS-229 Multigrid Collimator Parameters

	20 sec	1 min
W (μm)	51	152
t (μm)	51	152
θ_M (min)	40	120
L (cm)	52.40	
ℓ_1	20.72*	
ℓ_2	21.36	
ℓ_3	34.55	
ℓ_4	42.14	
ℓ_5	46.50	
ℓ_6	49.00	
ℓ_7	50.45	
ℓ_8	51.27	
ℓ_9	52.03	

*Relocated from 51.75 cm.

where λ is the X-ray wavelength. For our 20 sec collimators, this sets an upper limit wavelength of 25.6Å; the upper limit wavelength set by our spectrometer's scan range is 25.2Å. Lindsey (1977) has performed a complete Fresnel-Kirchhoff analysis of the multigrid collimator diffraction problem. The effect of diffraction is to broaden the central transmission lobe, lower the on-axis peak, and, for long wavelengths, to introduce side transmission lobes. Based on Lindsey's test cases, none of which closely resembles our collimator, we can expect some broadening of the central transmission lobe at wavelengths around 20Å. The response to an X-ray source uniformly filling the aperture would appear to be changed negligibly compared to that calculated for the no diffraction case.

III. Mechanical Design

The design strategy was to mount the grid assemblies firmly to a rigid reference surface, make provisions for small alignment adjustments, and, after the adjustments were complete, to fix the grids firmly in place. To accomplish this, the grids were first mounted onto frames, and the frames were, in turn, mounted within frame holders which made provision for the small adjustments. The holders were then screwed firmly into the housing and the adjustments were made. After the adjustments were complete the adjustment screws were glued in place. The alignment and assembly procedures are described in Section IV of this report.

Figure 3 shows a grid assembly mounted in the collimator housing. The grid is positioned on the frame, fitting snugly over the dowel pins, P. Next a .051 cm thick beryllium-copper grid press is placed on top of the grid and screwed down with eight 0-80 x 1/8" cap screws which are then secured with an adhesive. The frame is now ready to mount in the holder.

The frame is held in place in the holder by two 0-80 corner screws, C, which draw the frame against two hemispherical rockers shown in the diagram. At the left end the frame is retained by the two dowel pins, D, which slip fit into slots machined in the holder. Adjustments in the horizontal dimension are made using the push-pull screw pairs, A, which displace the levers, L. The force bears on the frame through the two hemispherical rockers. The arrangement allows for a motion reduction of about 5:1 so that one revolution of an 0-80 screw results in a grid motion of about 60 μm. Vertical motions are effected by adjusting the push-pull screw pair, B, to move the lever, H. The

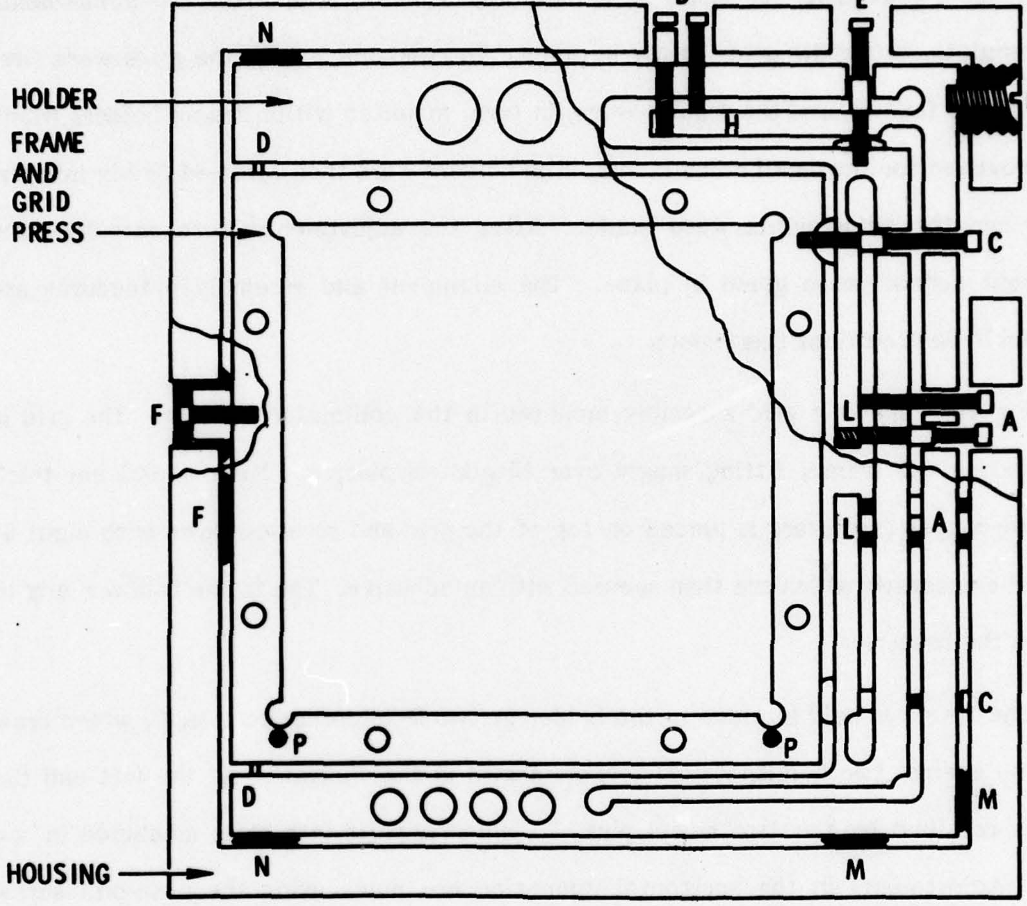

Fig. 3. Grid Assembly Positioned in the Collimator Housing with Cut-Aways of Mounting and Positioning Mechanisms

force bears on the pad held in place by the corner screw, E, and the inner part of the holder swings up and down. Again a motion reduction of about 5:1 is accomplished. Long screws are employed so that they can be glued in place with respect to the collimator housing when the alignment is complete. The initial assembly is made with short screws which permit the grids to be positioned along the length of the housing. The longer screws are then put in.

The frame assembly is held in the housing by screws passing through the 1/4 - 28 "mount point plugs", M and N. The M plugs form a three-point mount for the holders, and the N plugs are snugged against the holder after the M plugs are screwed down. The two cylindrical plugs, F, are installed after the alignment is complete. Their 0-80 screws are epoxied to the cylinders and then screwed into the frame. When the epoxy has cured, the hole in the housing around each cylinder is filled with a viscous epoxy. These last plugs provide added support for the grid frames so that they are not cantilever supported against gravity and launch vehicle vibration by the corner screws C.

The primary objective of the housing design was to provide stiffness in both torsion and bending. The instrument configuration constrained the housing to a rectangular cross-section; the best such tube would be monolithic. Since machining with conventional tooling is not feasible in the bore of a long rectangular tube, the housing was fabricated by joining two "U" sections of "Tenzaloy", a proprietary aluminum alloy,[1] using the "salt dip brazing" technique. By heating the Tenzaloy to 730 K (850°F) for six hours and allowing it to air cool one obtains a hardened stress-free structure that will maintain its figure throughout subsequent machining operations. By contrast, we were unable to obtain a stabilized, stress-free structure using 6061-T6 aluminum despite

[1] Federated Metals Division of American Smelting and Refining Co.

considerable effort to do so. Once the "U" channels were joined the collimator housing was finished by using conventional machining techniques. Since the optical bench for mounting the grid frame holders is defined by the adjustable mount point plugs, high precision machining was not required. The inside of the housing was finished to standard tolerances, and on the outside a machining allowance was left.

A three-point kinematic mount, with two points on the rear corners and one at the front center of the housing, was used. Best practice for the avoidance of sag in a gravitational field (see below) is to employ mounts as near as possible to the Airy points, the mounting points giving minimum deflection for a uniform beam in a gravitational field (see Blake et al. 1976). Space constraints inside our payload dictated the use of mount points at the housing ends instead. The mount is illustrated in Figure 4. At the left rear (in the figure) a cone and ball assembly is used to fix the collimator at one point. The strut on the right rear fixes the assembly in the vertical sense but allows small motions about the ball and cone axis. The height of the rear of the collimator is adjustable through the use of washers as shims on the two mounting assemblies. A ball and socket arrangement supports the front. The socket is part of a bridge piece across the front of the housing which allows very small deflections along the collimator axis but is otherwise stiff. The ball is screwed into the mounting plane, and its height may be adjusted by screwing it in or out. There is also provision for small adjustments of the mounting plane assembly along the horizontal axis that is perpendicular to the collimator look axis.

A first consideration in judging the adequacy of a collimator housing is the amount of sag in the Earth's gravitational field. The analysis for a uniformly loaded beam simply supported at its end points gives:

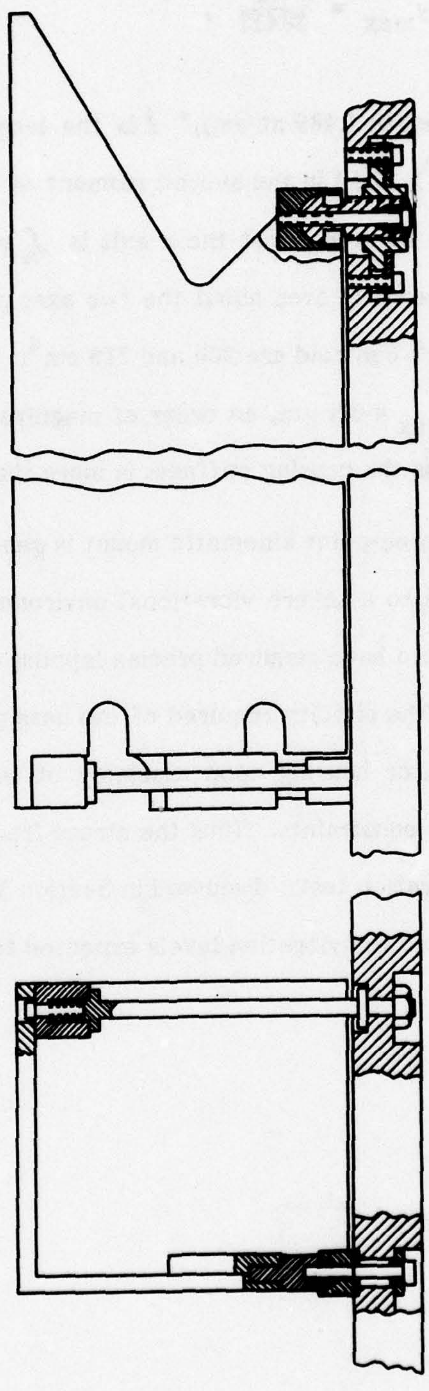

Fig. 4. Three-Point Mounting Provisions in Collimator Housing

$$y_{max} = \frac{5\,W\ell^4}{384EI}\,, \tag{5}$$

where W is the weight per unit length (.469 nt/cm), ℓ is the length (56.85 cm), E is Young's modulus (6.89×10^6 nt/cm^2), and I is the second moment of area. (In Cartesian co-ordinates the second moment of an area about the x axis is $\int_A y^2 da$, where da is an element of area.) The second moments of area about the two axes perpendicular to the look axis and through the collimator's centroid are 200 and 219 cm^4. Taking the lesser of these two values of I we obtain $y_{max} = 0.5$ μm, an order of magnitude smaller than our expected grid alignment errors. Thus the housing stiffness is more than adequate.

We note in passing that the three-point kinematic mount is generally regarded as a poor choice for a system subjected to a severe vibrational environment. On the other hand, use of a four-point mount would have required precise lapping of a very rigid base plate to form a mounting surface. The rigidity required of the base plate to prevent the coupling of stress into the collimator housing upon assembly of the payload was not obtainable within instrument weight constraints. Thus the stress-free three-point mount was adopted. The results of the vibration tests, discussed in Section VI, indicate that the chosen mount is adequate to withstand the vibration levels expected to be encountered at spacecraft launch.

IV. Alignment

The collimator alignment procedure is similar to that developed by Blake and his collaborators at Los Alamos Scientific Laboratories (Blake, et al. 1976). Figure 5 illustrates the set up. The grid adjustments are made using the two microscopes in the figure. Each microscope has at its tip a 45° prism so that one can look in a direction normal to the grids from the side, as is illustrated in the figure. Holes in the side of the collimator housing allow the microscopes to look in at each grid station and also allow small lights to be inserted to back light the grids. One such hole is shown at screw C in the upper right of Figure 3. Since some grids can only be viewed from one side, the tips of the microscopes are rotatable to allow viewing from front or rear. The microscopes have tungsten carbide buttons to bear on the granite surface plate and against the straight-edge. The alignment procedure is described in detail in the following paragraphs.

The first step in the assembly procedure was to inspect and select the grids to be used. The grid specifications required that the hole size not exceed the 51 μm specification by more than 7.6 μm and that all long distance measurements between selected points on the various grids not differ by more than 12.7 μm. For eleven-grid collimators, thirty grids were initially available from which to choose. The inspection procedure consisted of making specified measurements using a toolmaker's microscope with a micrometer-driven stage. For each grid the hole and bar widths were measured in both the horizontal and vertical direction for 24 randomly selected holes. In addition 17 specified long distance measurements (0.7 - 3.5 cm) were made on each grid. The measurements revealed a tendency for the holes to be somewhat larger than the nominal

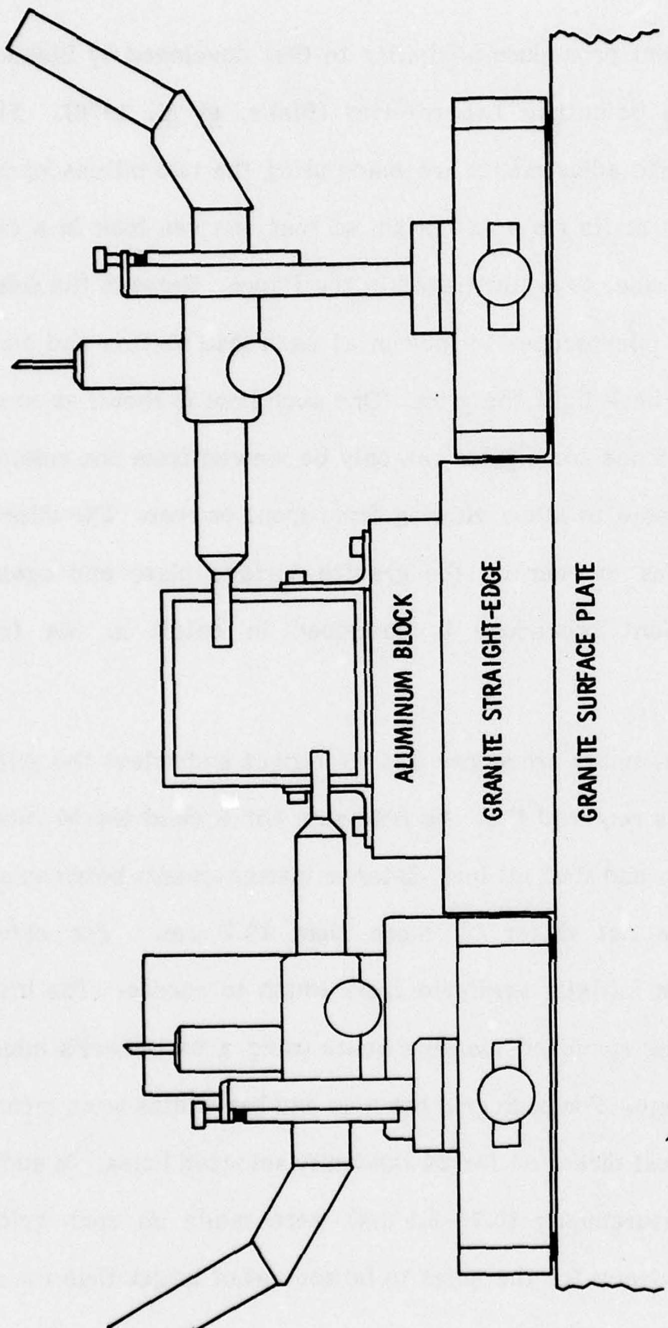

Fig. 5. Front View of Collimator Alignment Setup

51 or 152 μm, but a complete set of grids with no holes outside the 7.6 μm tolerance was available for the one arc minute collimator. Among the 20 arc second grids chosen for flight, seven had no holes outside of tolerance. The rest had no more than two hole or bar measurements (of 96) per grid outside tolerance. The 3.5 cm measurements revealed a maximum difference between two flight grids of 6 μm for the one arc minute collimator and 12 μm for the 20 arc second one. The standard deviation for similar measurements on the same grid was 5 μm. Since most of the grids had few or no out of tolerance holes, the flight grid selection was made so as to minimize the scatter of the long distance measurements.

The first step in preparing the housing is to insert the mount point plugs on the bottom and side and to adjust them so that the grid holders will all lie a fixed distance from the outside housing surface. The collimator, with the plugs in, is set on three wafers of precisely the same thickness. (0.635 cm) on a granite surface plate. Thus the outside of the bottom of the housing is parallel to the granite surface. A brass cylinder with a hole bored down its axis is set upon two more of the special wafers, and a stainless steel rod is slipped into the hole to stand upright on the two wafers. A height gauge is zeroed on the top of the rod. The cylinder is then located over a hole in the top of the housing opposite the plug to be adjusted, and the rod passes through the cylinder and rests upon the mount point plug surface, and its height is measured. If this measurement is nonzero, the rod is removed and the plug screwed in or out with a special wrench. This is repeated until the measurement is within 25 μm of zero. After all plugs on the bottom are so adjusted (to a height of 12700 ± 25 μm above the granite surface) the collimator is rotated about its long axis and the procedure is repeated for the side mount point plugs.

The grid assemblies are mounted in the housing, and the side screws are tightened while a rod presses the assembly against the M mount point plugs. The bottom screws are not inserted at this time. The collimator is mounted on the surface plate and adjusted until the upper outside surface is parallel to the surface plate and one side surface is parallel to the granite straight edge, to an accuracy of about 25 μm. Each grid has two fiducial marks on its margin, one in the field of view of each microscope. These marks each point to a row of holes, and the second holes in these rows are the grid adjustment references. After the housing has been adjusted, each grid's alignment is measured with respect to a standard grid (usually the front one). If necessary, some of the grid assemblies are slipped off their mount point plugs and the plugs are adjusted with a special wrench until all grids are within about 50 μm of a common axis. This step assures that the final adjustment can be made with the frame holder levers near the middle of their travel ranges.

The collimator is next dismounted, and the two rearmost grids are removed. The last three grids are so closely packed that they can be viewed with the microscopes only from the rear with the grids in back of them removed. Thus the last two grids must be inserted and aligned, one at a time, after all the forward grids have been aligned. The mount point plug screws are torqued down and the collimator is remounted on the surface plate for the final alignment. The front grid is taken as a standard, and the microscopes, equipped with a special reticle, are aligned on the reference holes with the carbide buttons against the granite straight edge. The microscopes are then moved to the grid to be adjusted, and the screws A and B are adjusted until the reference hole is centered on the crosshairs. From time to time the corner screws C and E are momentarily relaxed to

relieve strain. When the grid is properly aligned the corner screws C are torqued down and any further small adjustments needed are made. Throughout the procedure the microscope may be moved to the reference grid to recheck the crosshair setting. After all the mounted grids are adjusted the screws are fixed in place with Dow Corning #6-1104 adhesive, a space approved rubbery material that cures in a few hours at room temperature, and the plugs F are inserted and epoxied in place. The procedure must then be repeated for each of the last two grids. The close packing at the rear of the collimator has the result that the alignment of all the grids cannot be checked when the assembly is complete. The testing program described in Section VI serves as the final verification of alignment.

V. Ancillary Equipment

Each collimator is equipped with a flat reference mirror aligned so that its normal is parallel to the collimator X-ray axis. In addition, the 20 arc sec collimator carries two Refractosyn sun detectors, manufactured by HH Controls Co., Inc.,[2] also aligned to the X-ray axis. Refractosyns combine total internal reflection in a triangular prism with balanced photodetectors so that when they scan across the center of the sun the output current goes through zero and changes sign. Since each Refractosyn is sensitive in one dimension, two devices are required, one rotated 90° about the common axis with respect to the other. By a technique described in a separate report (Howey and McKenzie 1978) we found the angular deviation of the Refractosyn axis from the normal to its flat front surface. Thus, like the mirror, it could be adjusted using an autocollimator. The mounting and alignment of the Refractosyns and mirrors are virtually identical; we will describe the technique using the mirror as an example.

Figure 6 shows a mirror assembly. The two parts are held together by the thin central rod with threaded pieces on each end. Three adjustment screws fit into sockets on the rear piece, as shown. The mirror normal can be adjusted over a small range by means of small motions of the three screws. The "O" ring must be tightly compressed when the alignment is complete. If the range of adjustment allowed by this arrangement is insufficient to bring the mirror into alignment, the mount to the collimator may be shimmed; we have never had to resort to this procedure. When the alignment is complete the screws are glued in place using Dow Corning #6-1104 adhesive, and any unfilled part of the groove outside the "O"-ring is filled with Torr-seal.

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[2]U.S. Patent 3,137,794

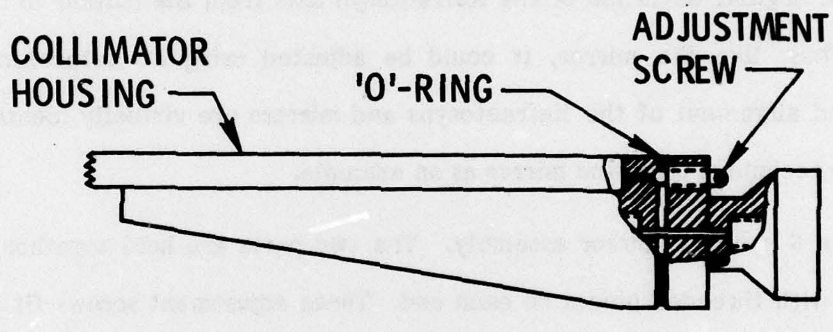

Fig. 6. Collimator Reference Mirror Assembly

Figure 7 shows the mirror alignment set-up. The procedure is performed after the grid alignment is complete so that the X-ray axis is parallel to both the surface plate and the granite straight edge. To define this axis we use a special mirror that can be positioned on the surface plate, against the parallel, such that its surface is normal to these planes. The microscopes are positioned to view a grid in the back half of the collimator so that, with occasional checks, they will reveal any collimator motion that might occur as the mirror is being adjusted. When the alignment is done the microscopes are used to recheck the collimator mounting. The autocollimator is mounted on a plate that may be translated along a second granite parallel perpendicular to the one on which the collimator is mounted. The autocollimator is zeroed on the special mirror then translated to view the collimator mirror, which is then adjusted until the reflected image is again zeroed. The autocollimator zero is then rechecked, the mount checked with the microscopes, and the mirror is epoxied in place. The autocollimator can be used to monitor the alignment to be certain that no shifts occur as the bonding agents cure. The alignment procedure, which takes less than an hour, results in a reference mirror whose axis is within a few arc seconds of the X-ray axis of the collimator.

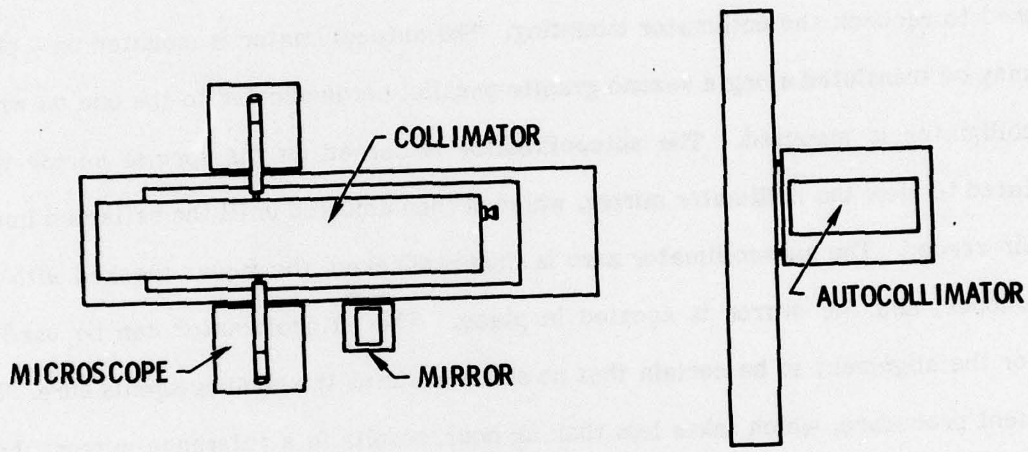

Fig. 7. Top View of Alignment Setup Arranged for Adjustment of a Reference Mirror

VI. Testing

After their final assembly and alignment, and prior to final delivery to the P78-1 spacecraft contractor, the collimators underwent a comprehensive series of tests. The tests can be broken down into three categories. The first tests used X-ray optics and were designed to verify the proper performance of the collimators themselves. A second series of tests verified the end-to-end performance of the spectrometer, including the collimators. Finally, vibration and thermal vacuum tests were performed on the entire instrument and on the collimators alone to assure that they would be able to survive severe launch and on-orbit environments. After the environmental tests, visual inspection, using the microscopes described in Section IV, and X-ray testing verified the survival of the collimators.

The set-up in Fig. 8, inside a vacuum tank, was the primary one used in X-ray testing the collimators. A glass strip was elastically bent into an approximation to a parabola with a point ($\sim 25\ \mu m$) X-ray anode at its focus. This arr ngement is described in a publication by Underwood (1977). X-rays from the anode strike the glass at grazing incidence and are reflected to form a parallel beam 0.5 cm wide, which fans out in the vertical direction (in and out of the paper in the figure). This 0.5 cm beam is much wider than the spatial period of the grids. In the vertical dimension, the beam width is αD where α is the collimator angular resolution and D is the distance between the X-ray source and the collimator. Since $\alpha = W/L$ where W is the hole width and L the collimator length, the beam width is WD/L; we sample D/2L grid periods for a hole-equals-bar collimator. For our tests D/2L = 2. Thus some care had to be taken to position the collimator vertically for maximum transmission, and the set-up was not

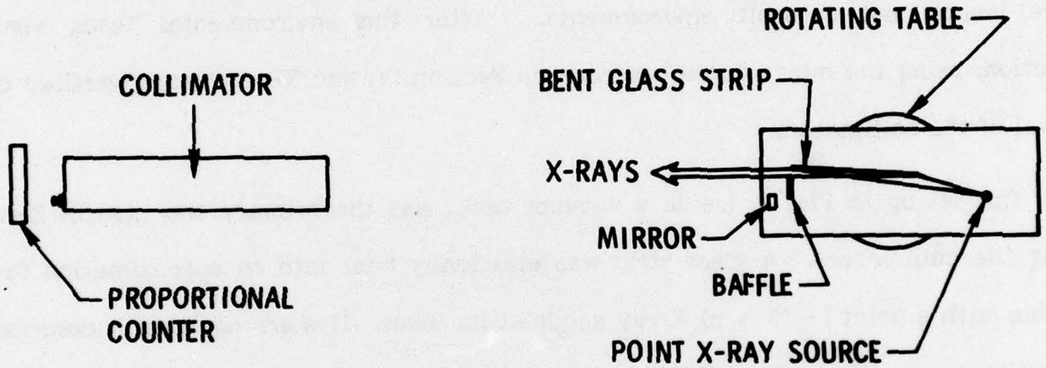

Fig. 8. Vacuum Chamber Setup Used to Search for Unwanted Side Transmission Lobes

suitable for absolute effficiency determinations. The purpose of the test, then, was to locate any side transmission lobes. The source was rotated about a vertical axis while the proportional counter counting rate was recorded on a strip chart. We found that the measured central peak FWHM (full width at half maximum) was $\sim$90 arc sec for the 20 arc sec collimator. Thus the incident beam had a FWHM greater than 1 arc min. This is substantially worse than the FWHM achieved earlier and reported by Underwood (1977), and this condition hindered the detection of close-in side lobes on the 20 sec collimator. The visual detection of grid displacements that would lead to such side lobes is, fortunately, very easy.

The test described in the previous paragraph was run numerous times on the various flight, spare, and prototype collimators built up during the course of the CRLS-229 program. From Figure 8 one can see that, as the table is rotated, the beam scans across the collimator. Thus in order to look at angles more than about 25 arc min off axis the collimator must be translated to the side to intercept the beam. In addition, a comprehensive side lobe search requires that the collimator be rotated 90° about the X-ray axis and the test repeated. The X-ray flux available set a lower limit of detection of about one percent of the peak transmission for side lobes of the 20 arc sec collimator, and about 0.3% of peak for the 1 arc min collimator. To qualify a collimator, a search out to $\sim$40 arc min off axis was required. For comparison, the solar angular diameter is 32 arc min. For one collimator we inserted the grids one at a time, starting with the front one, and ran an angular response test after each was added. The results showed good agreement with the predictions of COLLIE, a ray-tracing computer program for multigrid collimators. This gives us added confidence in the validity of the side lobe searches.

The main test of the SOLEX instrument consisted of irradiating the spectrometers with characteristic X-rays from a cooled Henke-type X-ray tube and recording the total detector counts as the crystals scanned over the angle range surrounding the angle given by

$$\lambda = 2d\sin\theta , \tag{6}$$

where λ is the X-ray wavelength and d is the crystal plane spacing. The X-ray source could be translated to irradiate a proportional counter with a pinhole window to monitor the incident X-ray flux. If the X-ray anode emissivity in photon-cm^{-2}-s^{-1}-sr^{-1} is ϵ , the counting rate of the monitor detector should be

$$R_M = (\epsilon A)\, \Omega_M \, \epsilon_{M\lambda} , \tag{7}$$

where A is the anode area, Ω_M the pinhole window solid angle, and $\epsilon_{M\lambda}$ the monitor detector efficiency. The expected number of counts in scanning the spectrometer over the line wavelength is

$$N_\lambda = \frac{I_o \, \epsilon_\lambda \, R_c(\lambda)}{\omega} , \tag{8}$$

where ϵ_λ is the SOLEX detector efficiency and $R_c(\lambda)$ the crystal integrated reflectivity at wavelength λ , ω is the crystal angular velocity, and I_o is given by

$$I_o = \epsilon \, A \, \Omega_c t_c = \frac{R_M \, \Omega_c t_c}{\Omega_M \, \epsilon_{M\lambda}} . \tag{9}$$

In the above expression Ω_c is the collimator FWHM field of view and t_c is the fractional grid open area ($\sim 1/4$). Thus,

$$N_\lambda = \frac{R_M \, \Omega_c t_c \, \epsilon_\lambda \, R_c(\lambda)}{\Omega_M \, \epsilon_{M\lambda}} . \tag{10}$$

Each spectrometer was tested at three angles, and the test sequence was run three times with one-minute collimators installed. The tests showed a variety of results with the ratio of measured to expected N_λ varying from less than 0.5 to more than 1.5. These variations underscore the complexity of this particular test. In testing a crystal spectrometer rocket payload by similar means, similar variations were observed (see McKenzie, et al. 1976).

A third test was used to measure the collimator transmission. The test collimator was placed on a table that rotated in both azimuth and elevation and was irradiated with X-rays from the Henke-type source. The table was adjusted in azimuth and elevation, and the source was positioned in height and translation, to achieve a maximum counting rate from a detector in back of the collimator. The source was then translated to irradiate a monitor counter, as in the systems test, and the measured counting rate ratio was compared to the expected ratio. This test was run only on the flight one-minute collimator, which was suspected of degraded performance. The measured ratio was 85 percent of that expected for an ideal collimator. This result is a satisfactory verification of collimator performance, in view of the possible errors in the test and the known small deviations of the collimator from the ideal (e.g., small grid misalignments and nonunifomity of the grids).

The collimators were subjected to a program of environmental tests. Prototypes were shaken individually and then inspected visually and tested using the bent glass collimator. In addition the prototypes were thermal cycled from $0^{o}C$ to $40^{o}C$. The results of these tests showed grid misalignments that would not significantly affect the performance of a one minute collimator but would render the 20 second one useless. For this reason, the CRLS-229 instrument was initially built up with two one-minute collimators. Thus all the systems tests were done with one-minute collimators only. The vibration tests were performed at a level of 10.1 g rms for one minute along each of the three experiment axes. This was followed by an X-ray systems test. Thermal vacuum tests were done in two sessions. In the first test the instrument was subjected to seven two-hour cold cycles at $0^{o}C$ and ten two-hour hot cycles at $40^{o}C$. In the second test three cold cycles at $-5^{o}C$ (2 hours) and three hot cycles at $+40^{o}C$ (2 hours) were undergone, as well as a 12 hour soak at $-5^{o}C$. Each session was followed by an X-ray systems test to verify collimator performance.

After delivery of CRLS-229 to the spacecraft contractor, the 20 second collimator design was modified to include the plugs, F, in Figure 3. The collimator was then built up, X-ray tested, vibration tested, X-ray tested, subjected to a thermal vacuum cycle ($25^{o}C$ to $-5^{o}C$ to $+40^{o}C$ to $25^{o}C$), and X-ray tested again. The final visual inspection of those grids that are visible when the collimator is completely assembled showed no misplacements greater than about 5 μm, or ten percent of a hole width. Testing with the bent glass optics revealed no side transmission lobes and no <u>obvious</u> degradation of transmission (recall that this is not a good transmission test). The 20-sec collimator was therefore installed in the CRLS-229 instrument and aligned with the 1 arc minute collimator using the reference mirrors, at the spacecraft contractor's plant.

VII. Summary

We have described the design, construction, and testing of two compact and lightweight multigrid collimators having angular resolutions of one arc minute and twenty arc seconds. The functional design follows, to a large extent, the procedure originated by McGrath (1968), but makes provision for grid nonuniformities and the inevitable small alignment errors or shifts. The mechanical design combines a firm and rigid mount with an intricate system of screws and levers that allow fine alignment adjustments to be made in a short period of time. When the alignment is complete the adjustment screws are bonded in place so that alignment is maintained over long periods of time and in severe environments. The assembly set-up is very similar to that described by Blake et al (1976) and employs microscopes, a granite surface plate, and granite straight edges to align the grids visually. The collimators were subjected to a comprehensive test program including visual inspection, performance tests using X-rays, checks with a ray-tracing computer program, and environmental tests to assure their proper performance in a space environment. They are currently installed in the CRLS-229 experiment in the P78-1 spacecraft, scheduled for launch in late 1978.

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